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Mark Kelley

Neeraj Gupta

Assessing the Effective CO_2 Storage Capacity of a Reservoir Using a Geomechanical Framework

A case study of a site in the Arches Province of the Midwest U.S.

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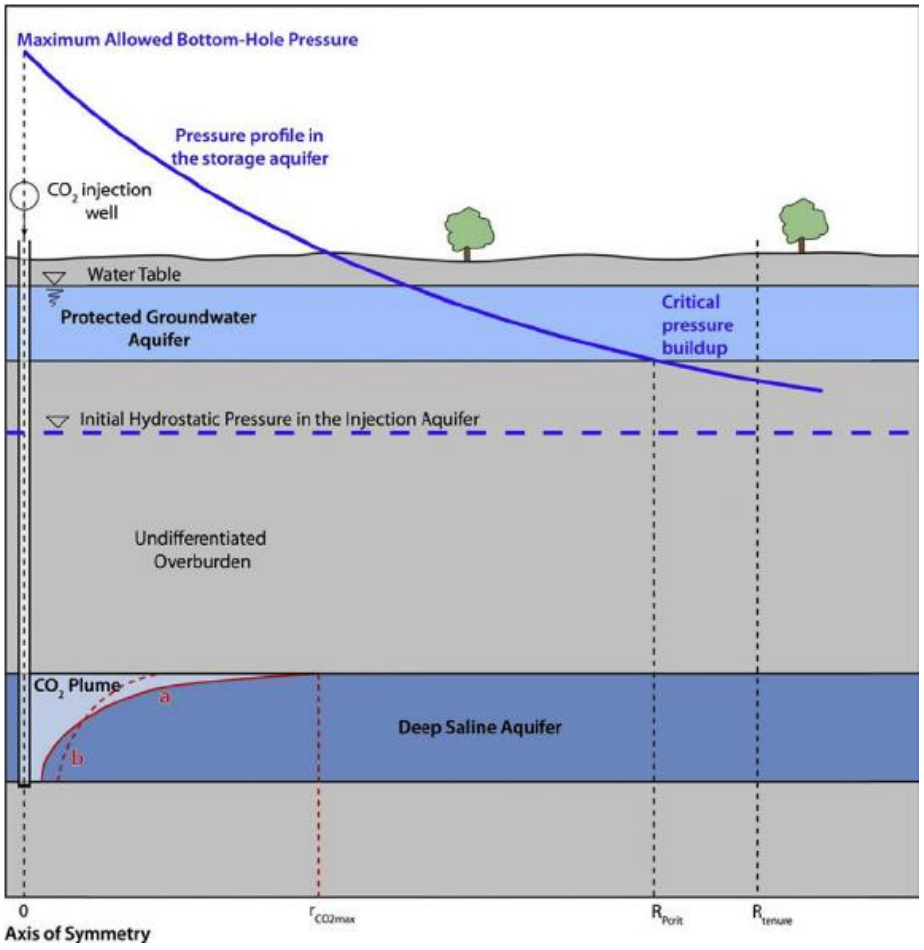
Outline

- Background
  - CO_2 storage in deep saline aquifers
  - Injection-induced stress changes in the reservoir
- Modeling the Arches Province Site
  - Methodology: workflow, model construction, assumptions
  - Sensitivity scenarios
- Analysis
  - Geomechanical impacts
  - Effective capacity estimate

CONCEPTUAL REVIEW

CO_2 Storage in Deep Saline Aquifers



- CO_2 injection into an aquifer creates a plume.
- Pressure profile generated.
- All injected CO_2 is stored either in supercritical state or by dissolution into the brine.

Bachu, S., 2015, Review of CO_2 storage efficiency in deep saline aquifers: International Journal of Greenhouse Gas Control, v. 40, p. 188-202.

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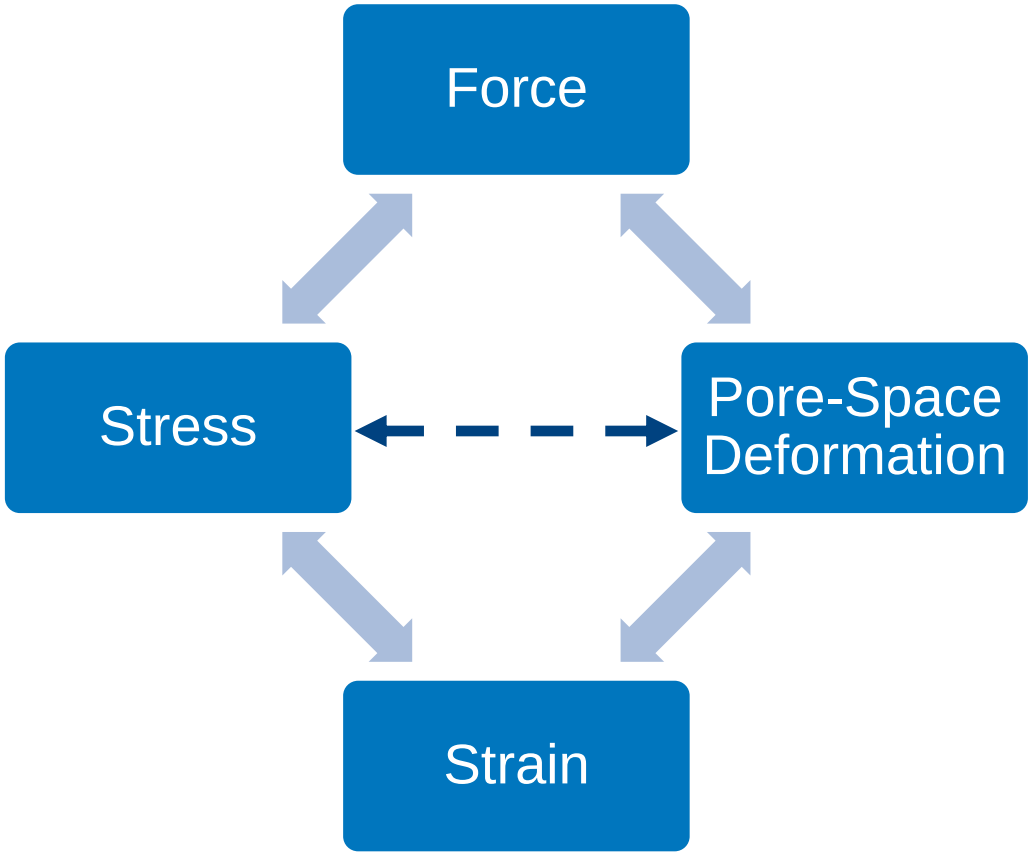
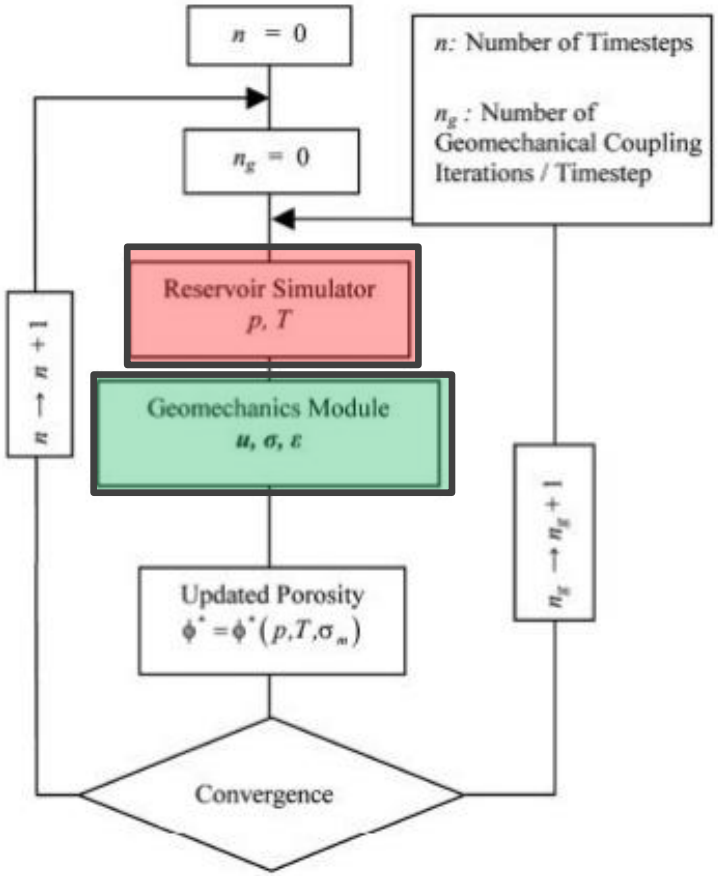
Coupled Fluid Flow – Reservoir Geomechanics Simulation





modified from Tran et al, 2005

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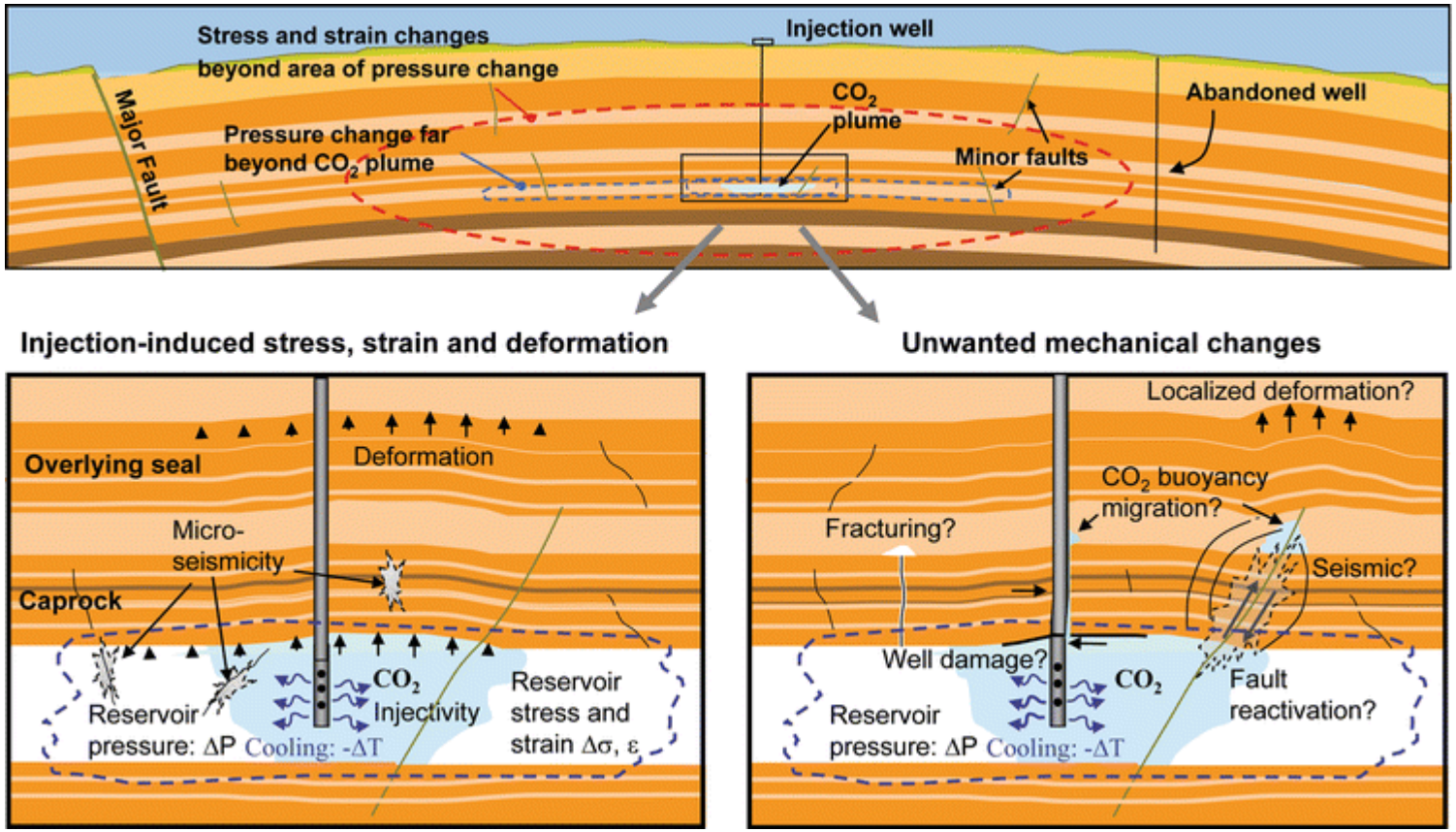
Geomechanical Impacts of Injection



Rutqvist, J. (2012). The geomechanics of CO_2 storage in deep sedimentary formations. Geotechnical and Geological Engineering, 30(3), 525-551.

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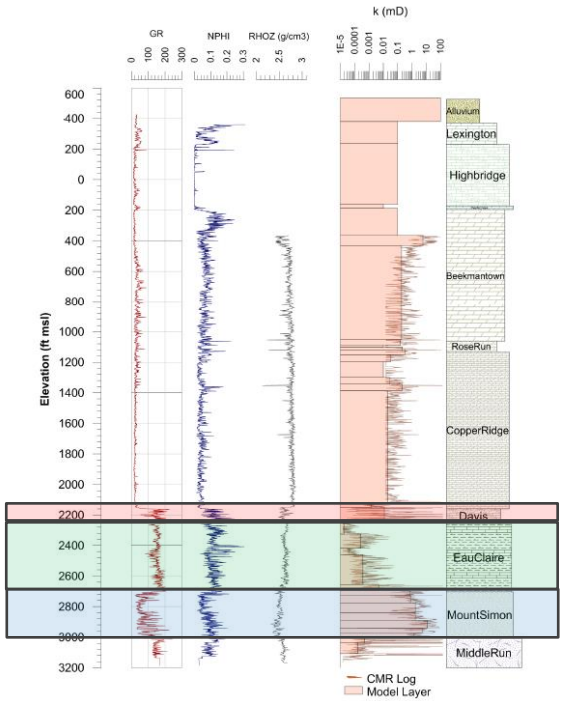
Overview

Geologic/Geomechanical Properties

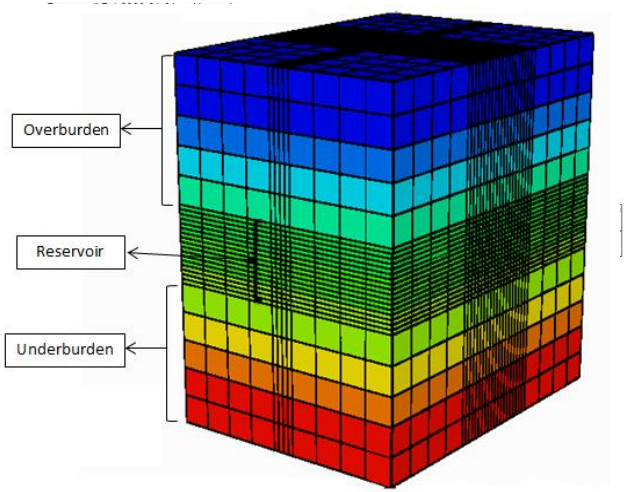


Caprock
Intermediate

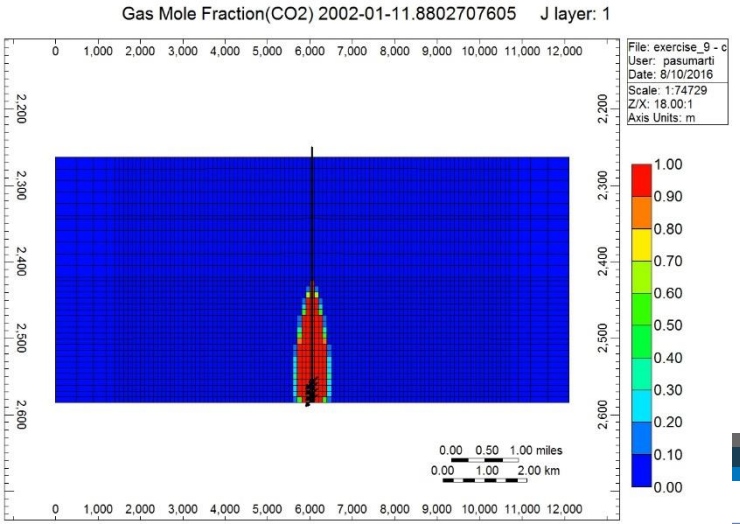
Aquifer

Delineated geomechanical units

Reservoir Model



CO_2 Injection



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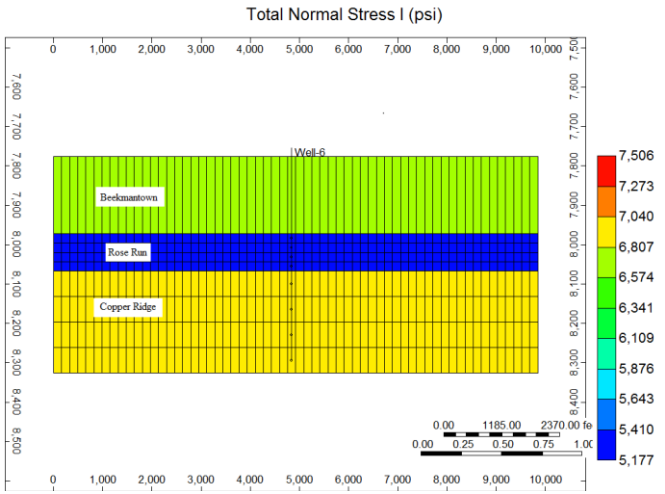
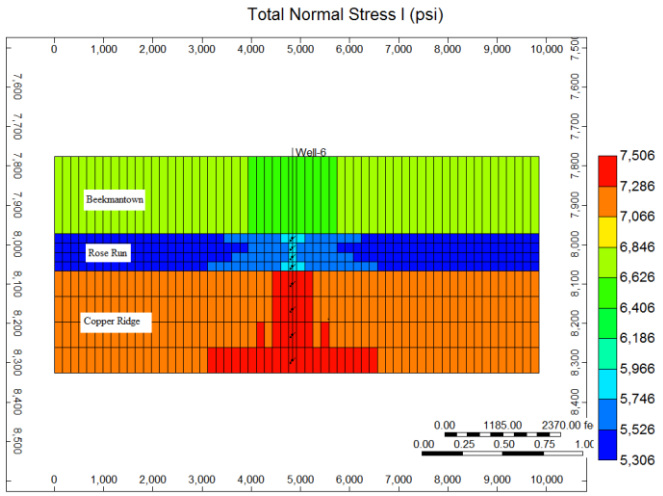
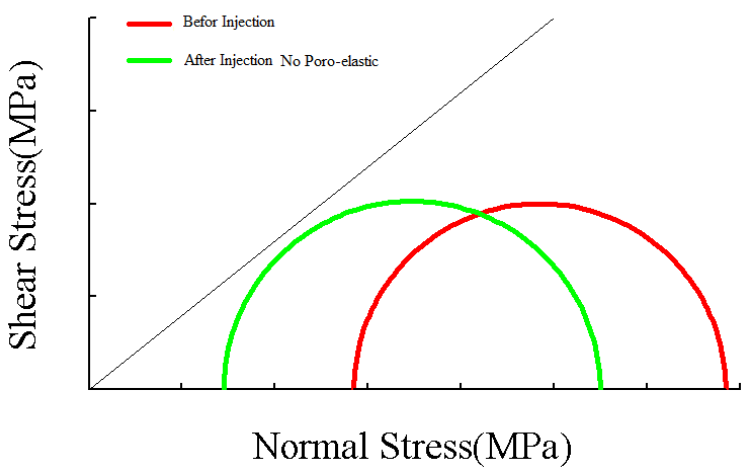
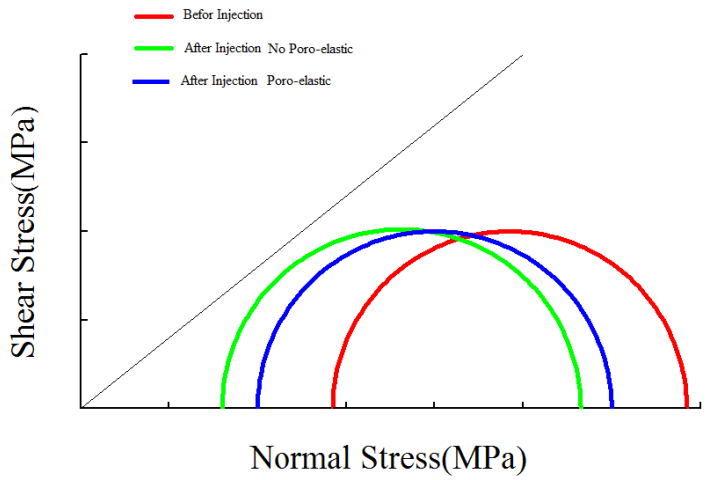
Mohr Circle Analysis



Total stress increases as a result of injection







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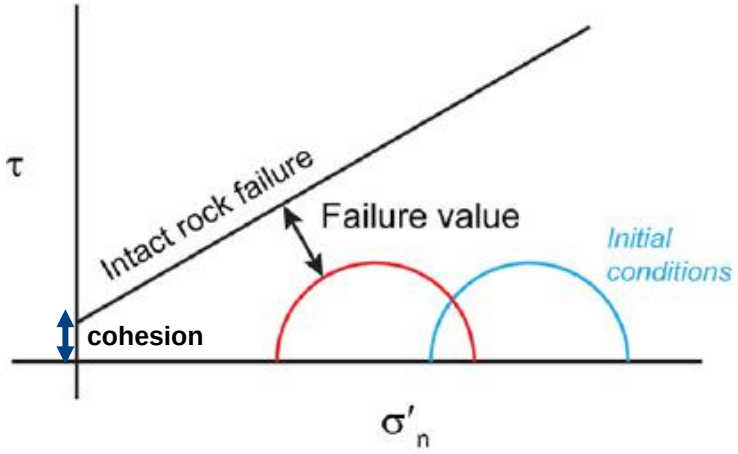
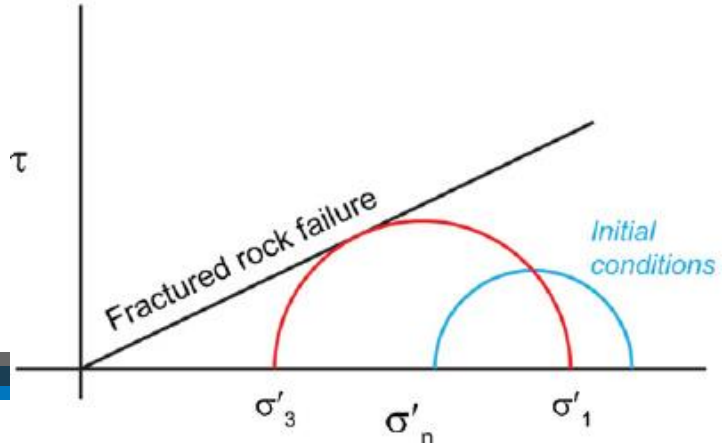
Intact & Fractured Rock Failure

(a) *This case is for illustrative purposes only – normally the Mohr circle would not move without changing size in a real injection scenario.*



(b) *This case is illustrative of injection in a strike slip stress regime where the Mohr circle enlarges due to the poroelastic effect.*



- Shear failure is said to occur if the Mohr circle plotted after injection hits the failure envelope.
- Distance from the envelope implies minimal risk of fracture activation.
- A weak or highly naturally fractured rock has a very low value of rock cohesion.

Olden, P., G. Pickup, M. Jin, E. Mackay, S. Hamilton, J. Somerville, and A. Todd. 2012. Use of rock mechanics laboratory data in geomechanical modelling to increase confidence in CO2 geological storage. International Journal of Greenhouse Gas Control, 11, 304-315.

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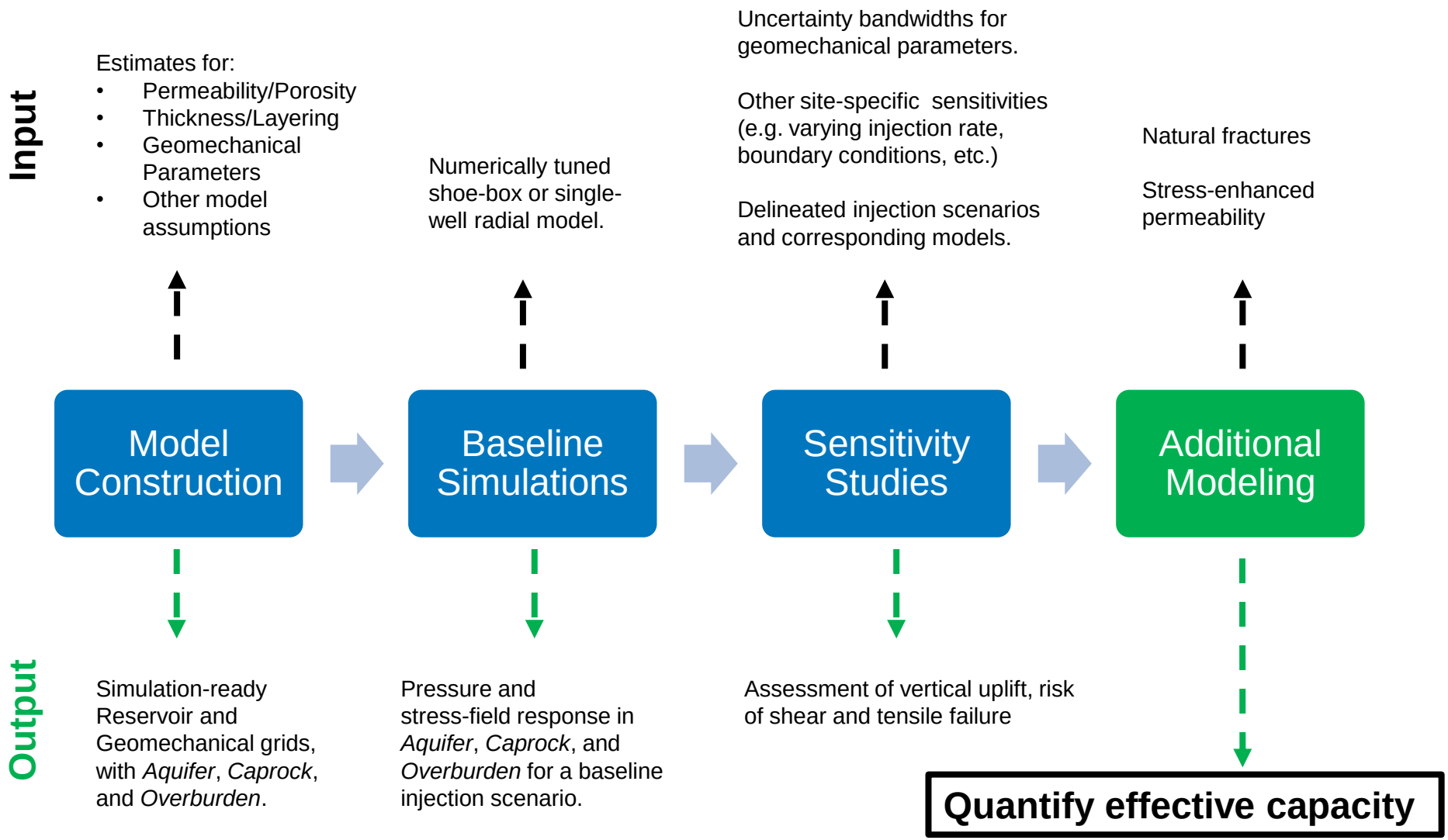
MODEL DEVELOPMENT

Analysis Framework



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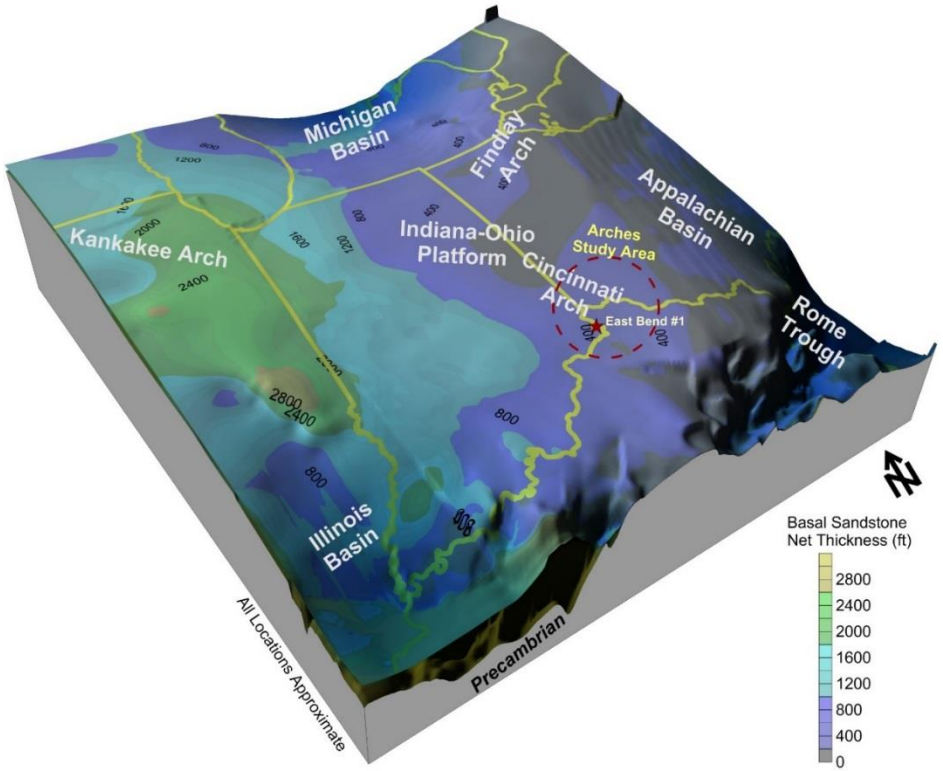
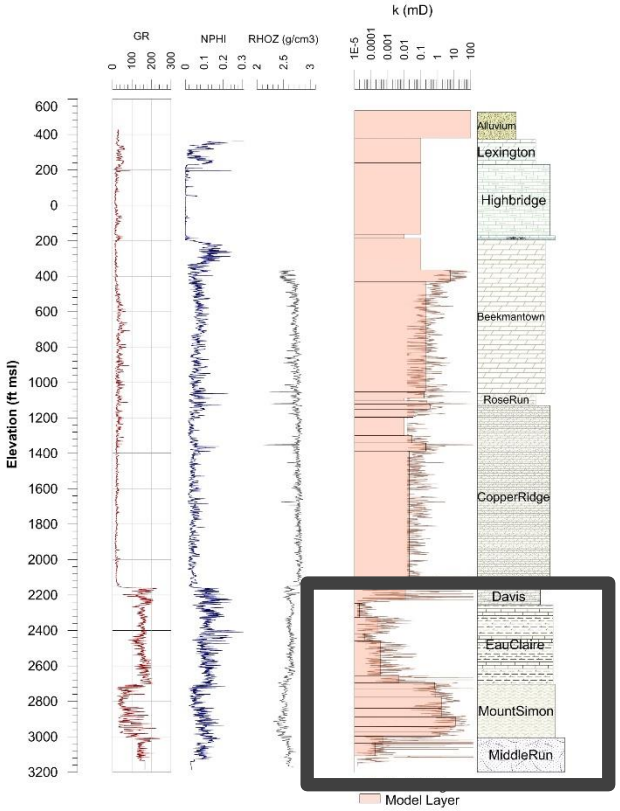
Arches Province in the Midwest US: East Bend Well Site





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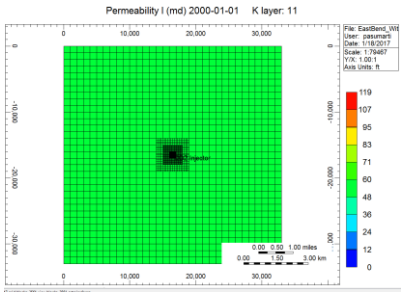
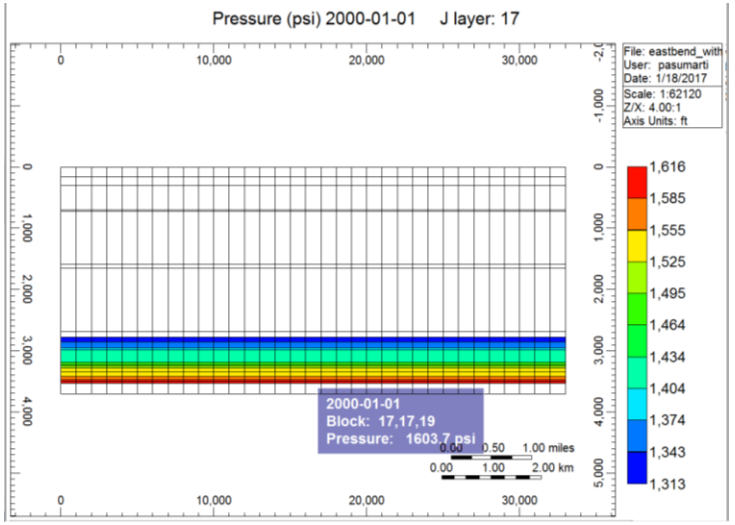
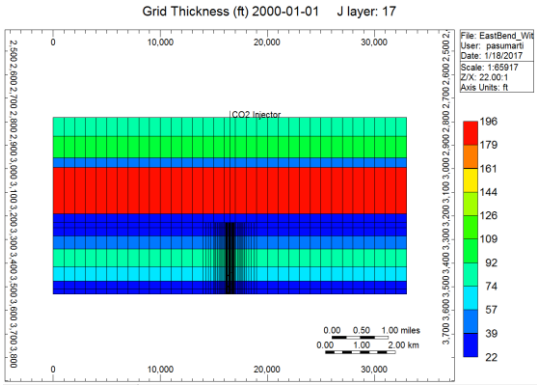
Model Construction

- 25,000 Acres
- 1000 x 1000 ft
- Grid refinement around Injector
- 30 years of injection

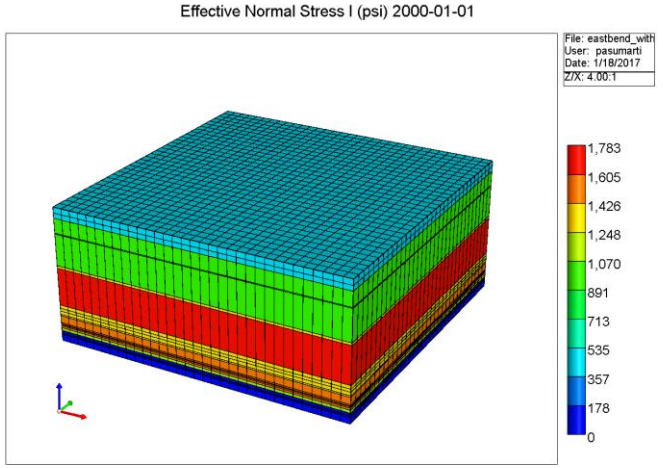


- Collocated Geomechanical and Reservoir grids
- Middle Run (underburden) to Surface.
- Log or literature-based stress gradients, static Young's modulus, Poisson's ratio





- Davis overlying the Eau Claire overlying the Mt. Simon
- 0.733 psi/ft injection limit or 2500 psi in Mt Simon.
- Assumptions for relative perm, homogeneity, etc.



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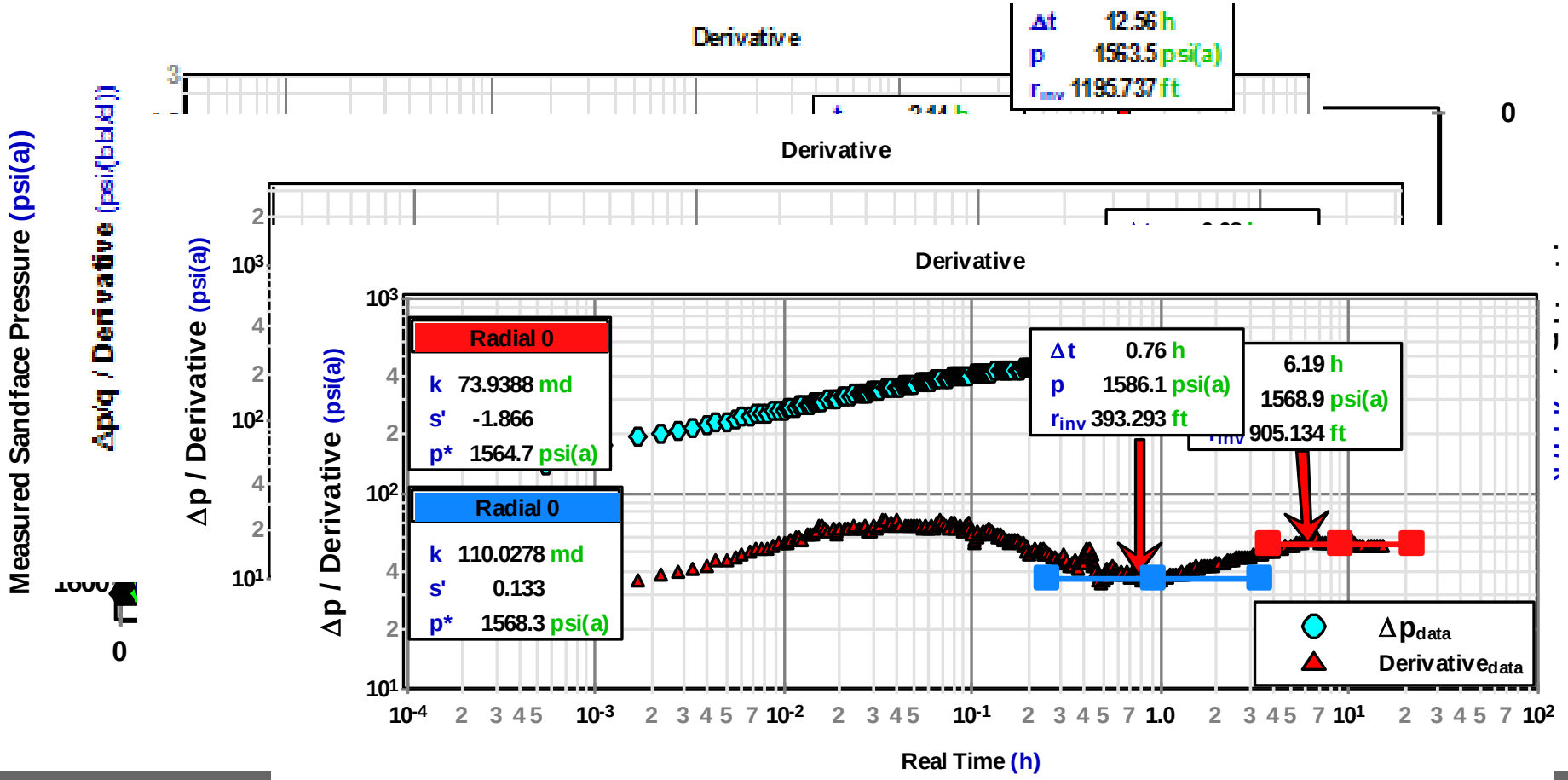
Characterization:
Permeability

- Pressure Transient-Analysis on 3 brine injection fall-off tests
- ~1000 ft radius of investigation



Battelle. 2010. CO2 Injection Test in the Cambrian-Age Mount Simon Formation, Duke Energy East Bend Generating Station, Boone County, Kentucky. Conducted by the Midwest Regional Carbon Sequestration Partnership (MRCSP). Morgantown, WV: U.S. Department of Energy, National Energy Technology Laboratory, DOE-NETL Cooperative Agreement DE-FC26-05NT42589.

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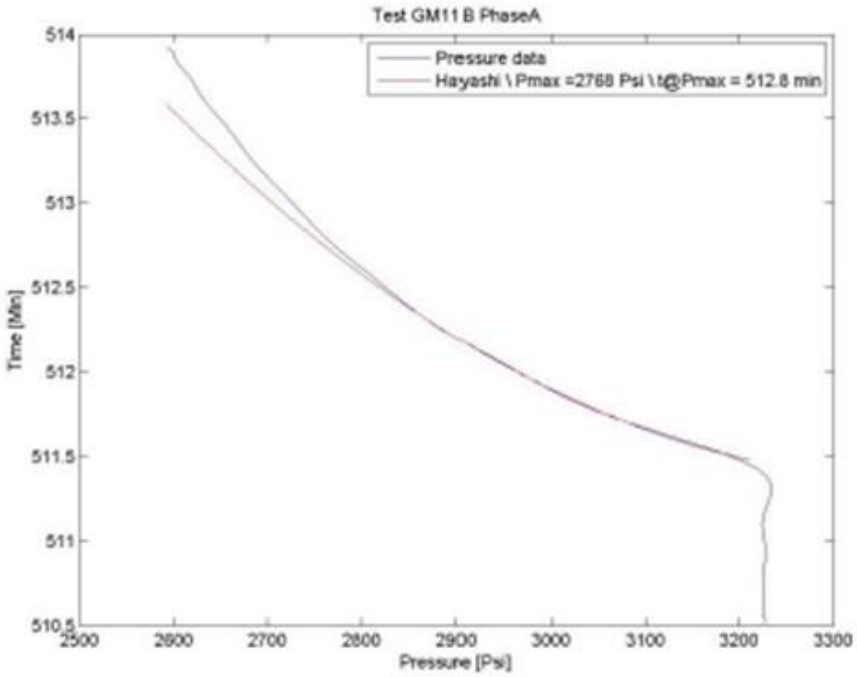
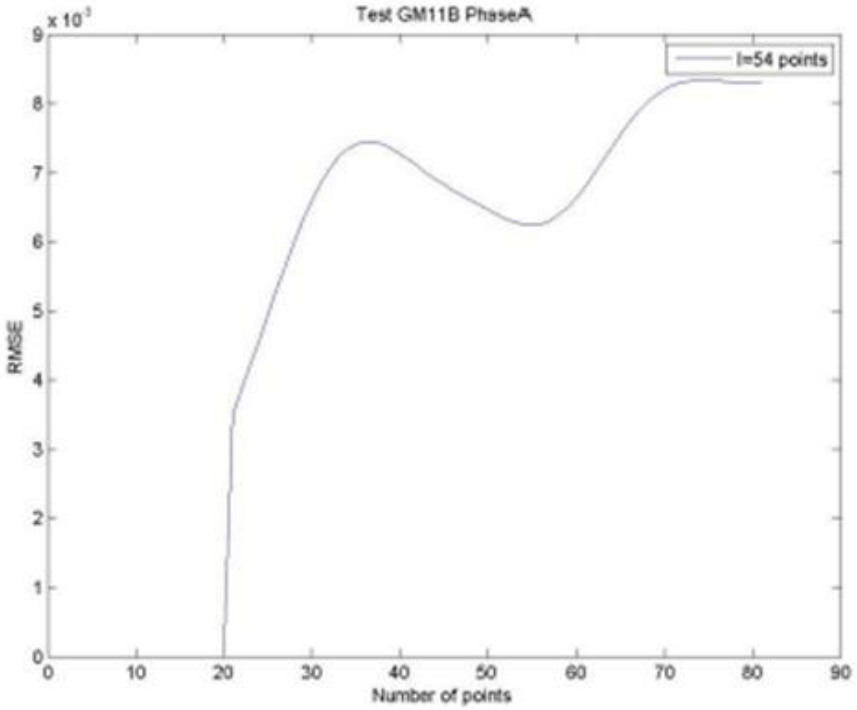
Characterization:
Minimum Horizontal Stress

Log, mini-frac test data and literature-based regional geomechanical trends enable constraining the stress in the Mt. Simon.





Cornet, F., and Battelle. 2014. Results from the In Situ Stress Characterization Program, Phase 1: Hydraulic Tests Conducted in the FutureGen Stratigraphic Pilot Well. Conducted by The FutureGen Industrial Alliance, Inc., . Washington,DC: U.S. Department of Energy, DOE Award NumberDE-FE0001882

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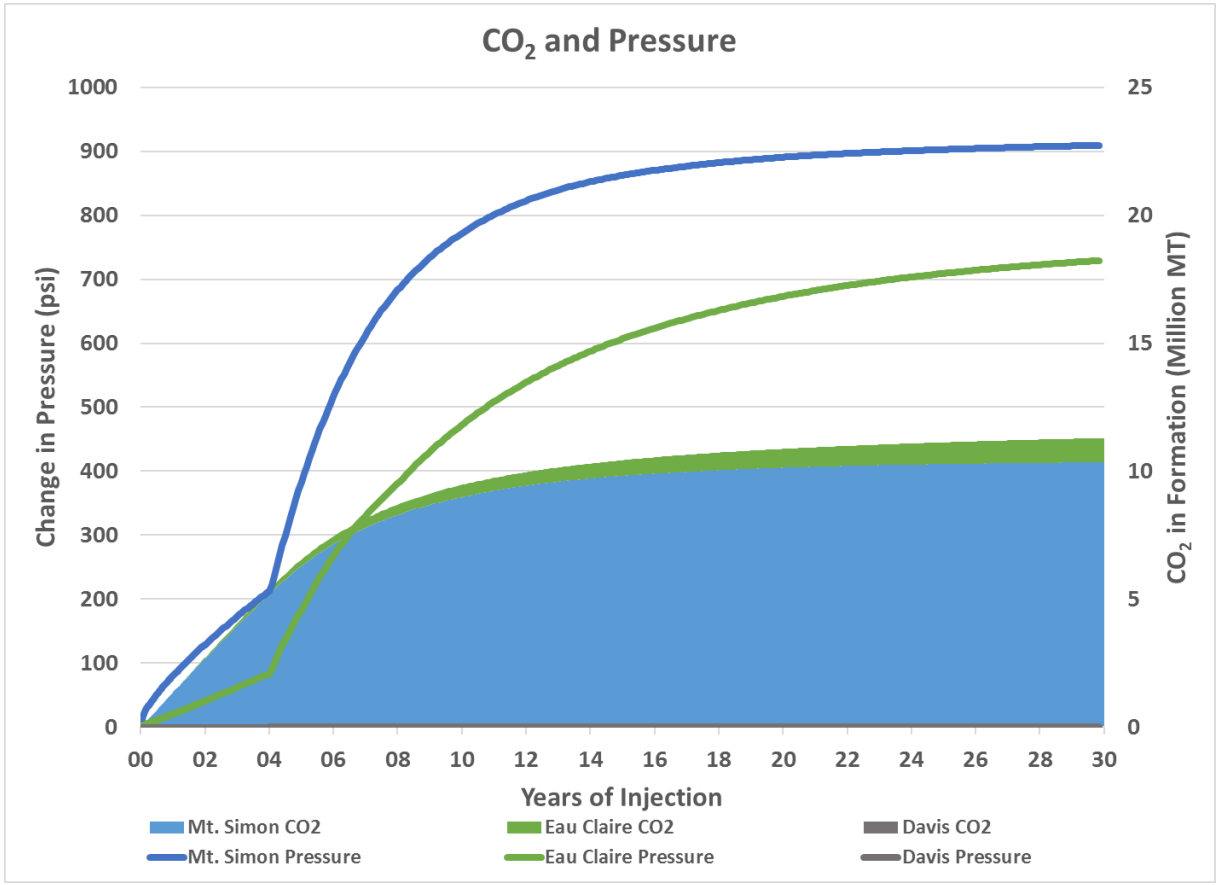
Sensitivity Scenarios

Scenario #	Boundary Condition	Biot's Coefficient	Young's Modulus	Max. Horizontal Stress Gradient
1. Base Case (Most Conservative)	Closed	1	Low	High
2.	Closed	1	Low	Low
3.	Closed	1	High	Low
4	Closed	0.8	High	Low
5 (Most Optimistic)	Open	0.8	High	Low

RESULTS AND ANALYSIS

Injection into the Mount Simon:
CO_2 Volumes and Pressure Increase



- Δp of ~900 psi in the Mt. Simon.
- Δp of ~725 psi in the Eau Claire.
- Approx. 11.25 million MT of CO_2 stored.
- ~1 million MT of CO_2 migrates upward into the Eau Claire.

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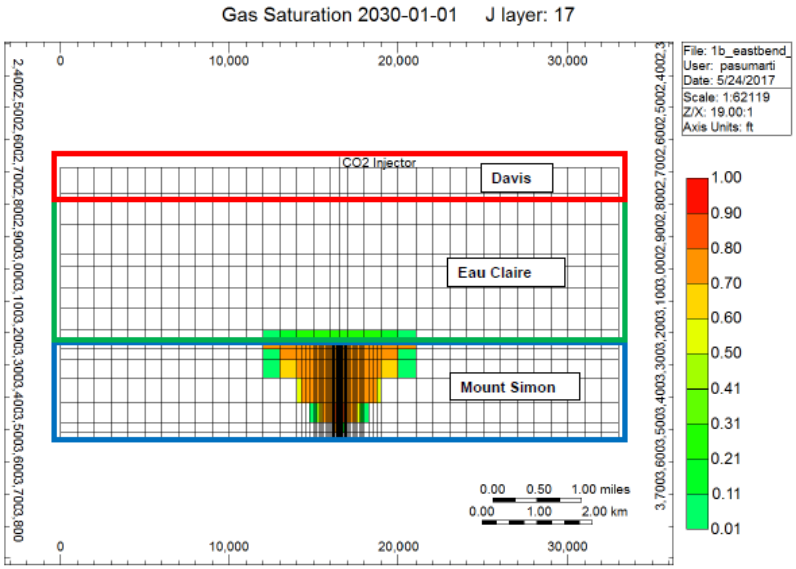
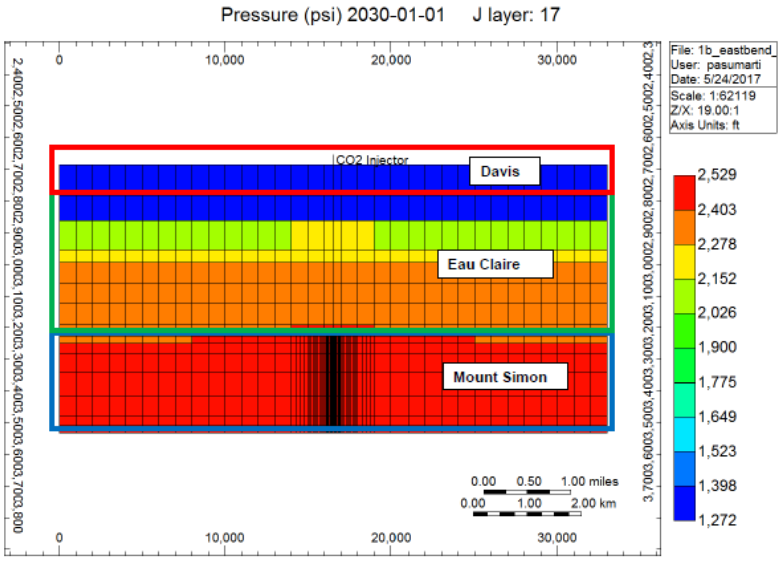
Injection into the Mount Simon:
CO_2 Plume and Pressures Attained

Gas Saturation



CO_2 plume is around ~5000 ft wide and penetrates up to lower Eau Claire.

Pressure



Lower Eau Claire pressure increases to ~2300 psi.

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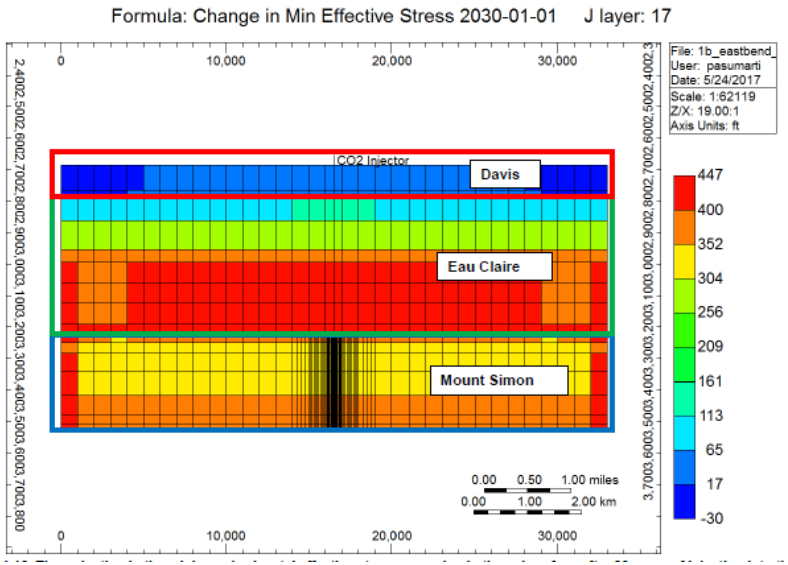
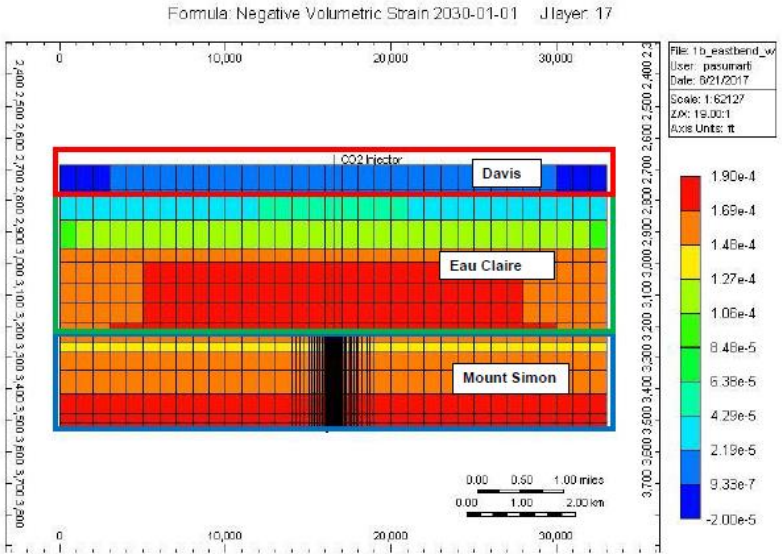
Injection into the Mount Simon:
Stress-Strain Impact

Δ Min. Effective Stress



Reduction in effective stress is more pronounced in lower Eau Claire.

Volumetric Strain



Pore-space deformation occurs mostly in the Eau Claire and Mt. Simon.

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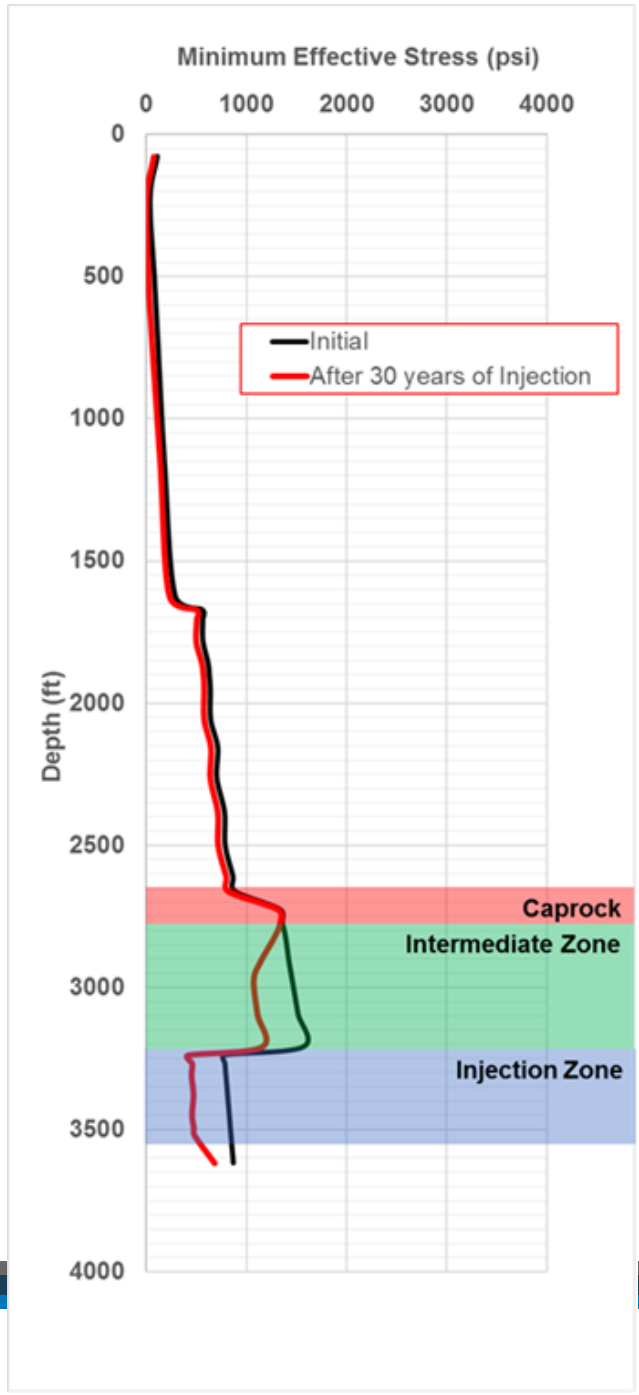

Injection into the Mount Simon:
Localized Stress Effects

- The minimum effective stress-profile from the underburden to the surface before and after injection.
- Negligible impact on layers caprock and above.

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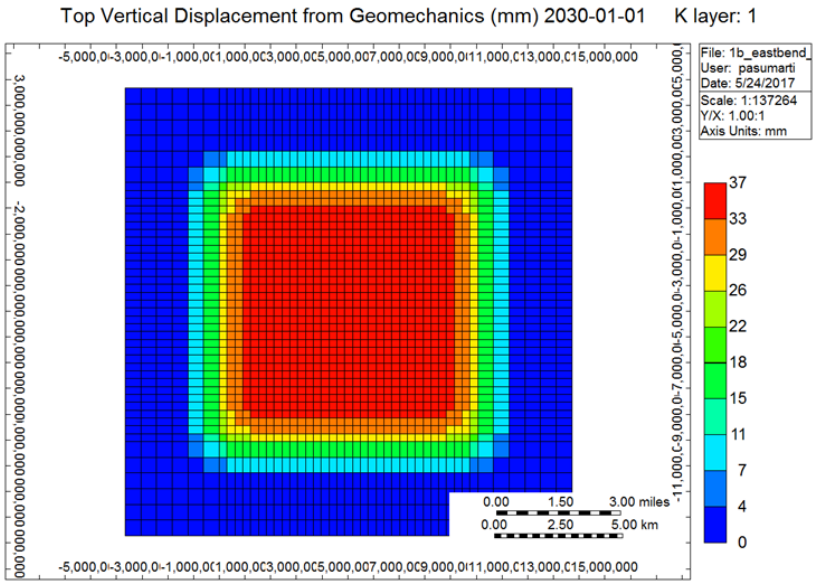
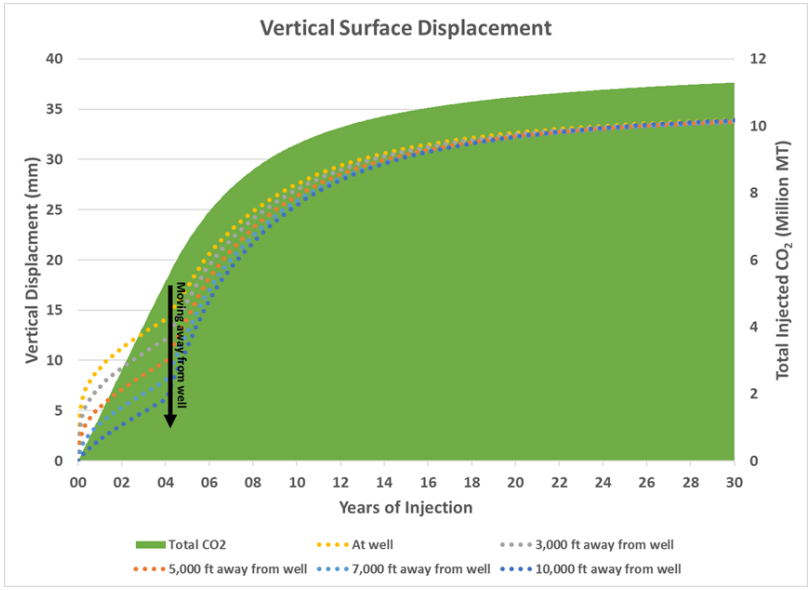
Injection into the Mount Simon:
Surface Uplift

Areal Displacement



Near uniform uplift across 25,000 acres at the end of injection.

Areal Displacement w.r.t. CO_2 Volume



Surface uplift of approx. 32 mm with ~11.25 million MT of injection.

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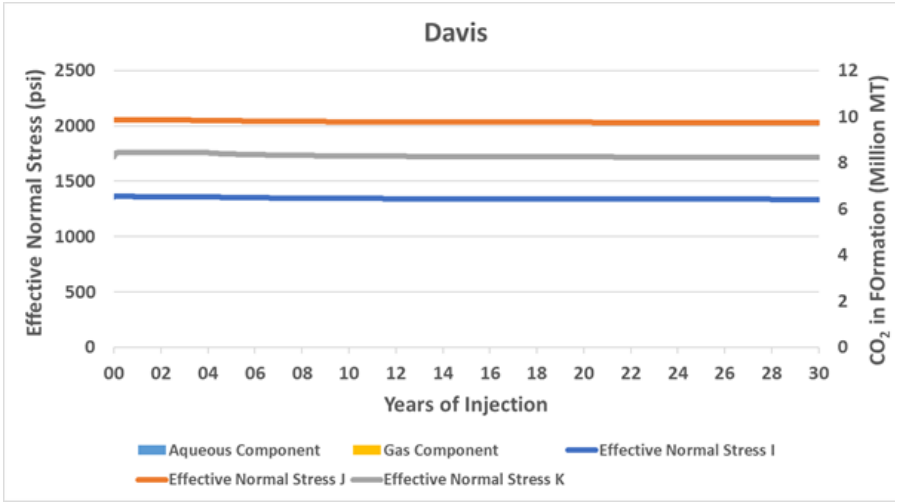
Injection into the Mount Simon:
Caprock Integrity (Davis)

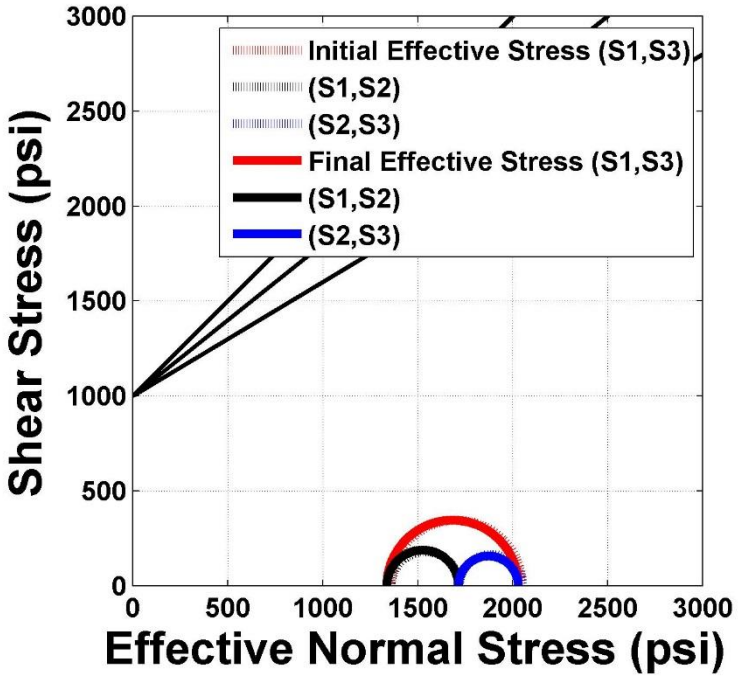
Principle Effective Stresses



Stresses in caprock are unchanged.

Mohr Circle

No shear or tensile failure.



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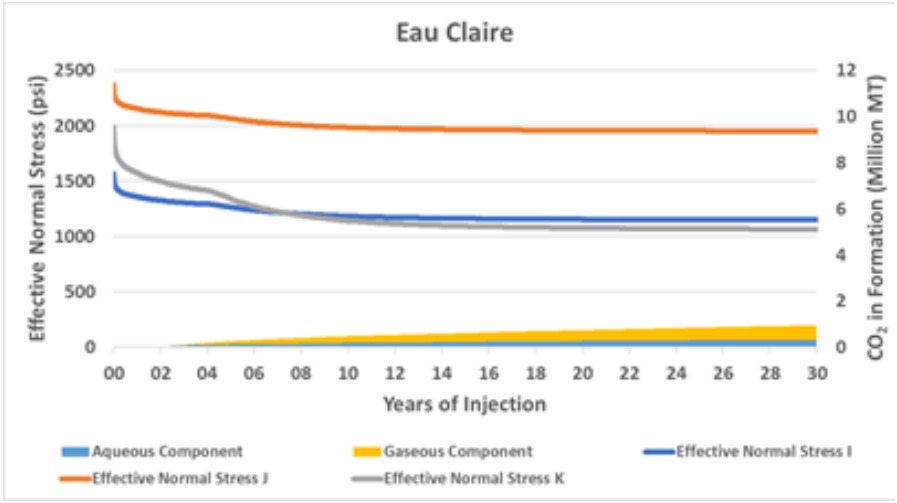
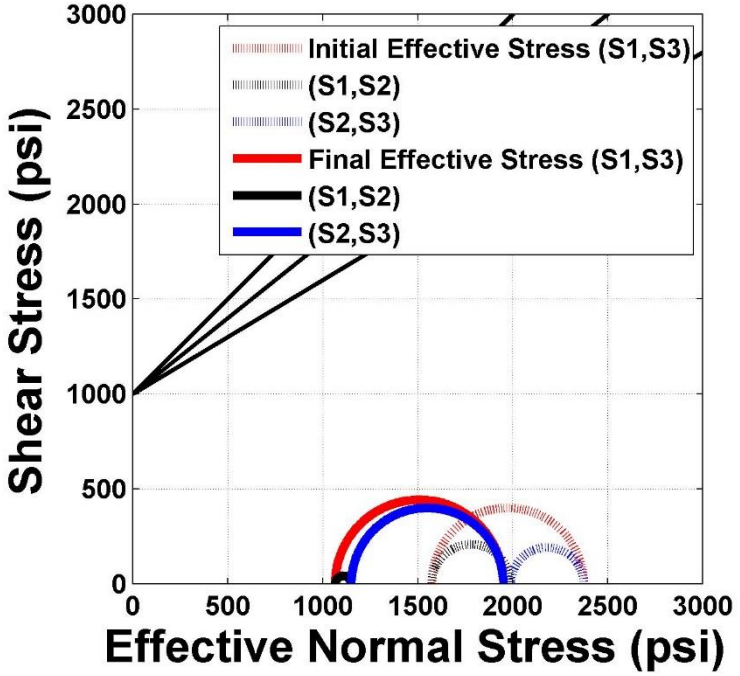
Injection into the Mount Simon:
Intermediate Zone Integrity (Eau Claire)

Principle Effective Stresses



Mohr Circle

No shear or tensile failure.



Vertical stress affected more than horizontal.
Regime change after 8 years of injection.

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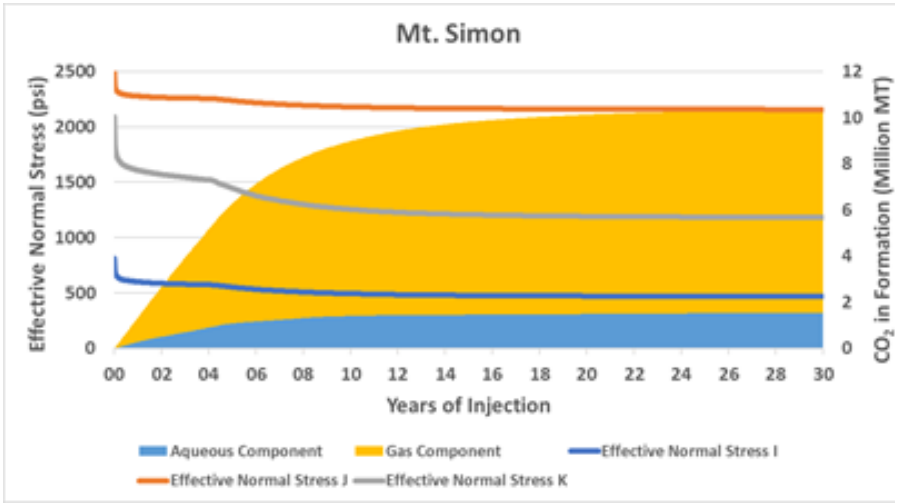
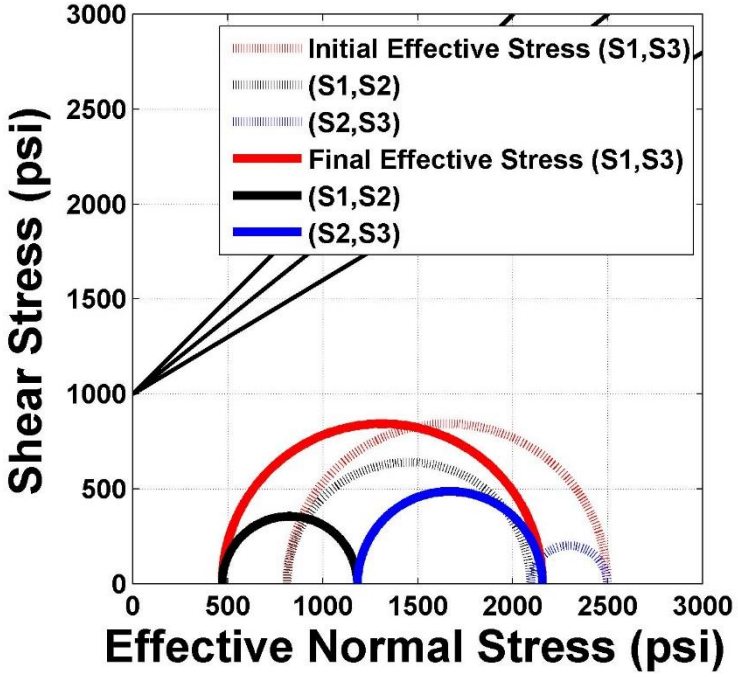
Injection into the Mount Simon:
Reservoir Integrity

Principle Effective Stresses



Mohr Circle

No shear or tensile failure.



Vertical stress affected more than horizontal.
No regime change.

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Sensitivity Scenarios

Scenario #	Shear Failure?	Tensile Failure?	Surface Uplift (mm)	Storage Capacity (millions of MT)
1 - Base Case (Most Conservative)	No	No	32	11.25
2	No	No	32	11.25
3	No	No	27	11.25
4	No	No	22	12.5
5 (Most Optimistic)	**No**	**No**	**1.2**	**38.25**

Summary

- Simulations suggest minimal risk of tensile or shear failure.
  - Minimum effective stress in all three zones is >500 psi.
  - Even the most conservative shear envelope is sufficiently distant from Mohr's circles.
- Up to 32 mm of uplift may be expected.
- A stress-regime change may occur in the Intermediate Eau Claire
  - Simulations do any indicate that this poses any threat to the operation.
- Evidence in literature for optimistic modelling conditions.
- **Conservative estimate of effective capacity is ~11.25 million MT.**

THIS RESEARCH WAS SUPPORTED BY THE U.S. DOE / NATIONAL ENERGY TECHNOLOGY LABORATORY (CONTRACT DE-FE0023330) AND THE OHIO DEVELOPMENT SERVICES AGENCY OHIO COAL DEV. OFFICE (GRANT CDO-D-14-17).